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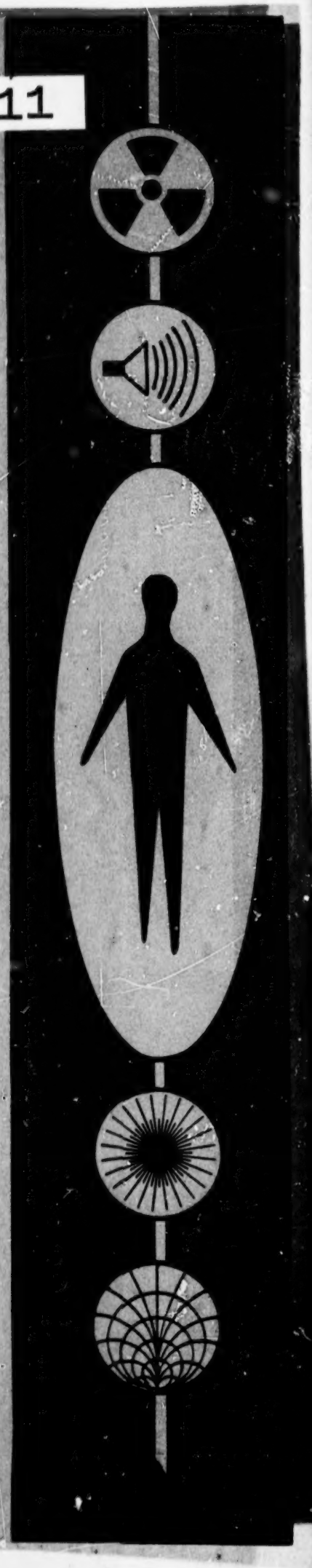
Biological Aspects of Ultraviolet Radiation

A Review of Hazards



U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
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Biological Aspects of Ultraviolet Radiation

A Review of Hazards

by

William M. Leach

September 1970

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Environmental Health Service
Bureau of Radiological Health
Rockville, Maryland 20852

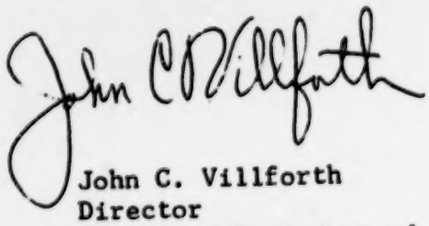
FOREWORD

The Bureau of Radiological Health, formerly the National Center for Radiological Health, carries out a continual national program designed to reduce the exposure of man to hazardous ionizing and non-ionizing radiation.

The Bureau publishes its findings monthly in Radiological Health Data and Reports, Public Health Service numbered publications, appropriate scientific journals, and in Division-sponsored technical reports.

The technical reports published by the Division of Biological Effects contain information generated by the Division staff which is timely and useful to the radiological health program. Subjects covered by these reports are varied, for the Division is charged with developing -- through animal investigations and population studies -- knowledge of the biological effects of radiation delivered to man from his environment and from his use of substances and devices that emit radiation. The reports are distributed to persons and repositories that have expressed an interest in the biological effects of radiation; in addition, the reports are available from the Clearinghouse for Federal Scientific and Technical Information.

Readers are encouraged to report omissions or errors to the Bureau. Your additional comments or requests for further information are also invited.



John C. Villforth
Director
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PREFACE

Recognition of the extent of man-made electromagnetic radiation in the environment prompted the passage of Public Law 90-602, "Radiation Control for Health and Safety Act of 1968." The Department of Health, Education, and Welfare was authorized to develop and administer programs to control certain types of electromagnetic radiation associated with potential health hazards. The development of the control program has required the redirection of some resources which were concerned with continuing problems of ionizing radiation.

In order to estimate the relative risks of various types of radiation, staff of the Bureau of Radiological Health reviewed the scientific literature on biological effects of the radiations. To date, three summary reports have been made available. They summarize the biological effects of microwave, laser, and, in the present review, ultraviolet radiations. The summaries are useful "starting points" for each type of radiation. They are not, however, definitive. In the development and continuing evaluation of the radiation control programs, we welcome comments and suggestions from all persons who are concerned with radiological health.

William A Mills

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Director
Division of Biological Effects

ACKNOWLEDGEMENT

I am indebted to Dr. J. G. Carlson for sharing some experiences concerned with ultraviolet interests of the U. S. Public Health Service during World War II; to Dr. Darrell Q. Brown for measuring the ultraviolet power density responsible for a corneal injury; and to both Dr. Carlson and Dr. Brown for their comments about the manuscript. The support and patience of colleagues and coworkers in the Bureau of Radiological Health during the preparation of the manuscript are deeply appreciated.

DISCLAIMER

The use of commercial products or mention of private firms in no way constitutes endorsement by the U. S. Public Health Service or its affiliates.

CONTENTS

Foreword iii
Preface v
Introduction 1
Nature of Ultraviolet Radiation 2
Production of Ultraviolet Radiation 2
Transmission of Ultraviolet Radiation 4
Mode of Action of Ultraviolet Radiation on Biological Tissues 6
Physical Factors Influencing Tissue Damage 13
Whole Body Exposure 13
Critical Organs 14
Cumulative Effects 16
Applicable Standards for Ultraviolet Exposure of Humans . . 16
Summary 18
References 19

TABLES

1. Wavelengths of Major Emission Lines of Mercury Arcs Below 4000 Å 3
2. Radiation Distribution from Incandescent Lamps 5
3. Degree of Erythema Produced by Exposure to Summer Noonday Sun 14

BIOLOGICAL ASPECTS OF ULTRAVIOLET RADIATION
A REVIEW OF HAZARDS

INTRODUCTION

Public Law 90-602, "Radiation Control for Health and Safety Act of 1968", provides that the Secretary of Health, Education, and Welfare is responsible for the protection of public health from radiation emissions from electronic products. One of the radiation emissions to which the Act is directed is ultraviolet radiation, the region of the electromagnetic spectrum between visible light and x rays.

Ultraviolet radiation was discovered in 1801 when J. W. Ritter observed blackening of silver chloride which was placed in the dark region beyond the violet end of the visible spectrum. Radiobiological research with ultraviolet has advanced to a point where specific ultraviolet-induced lesions are identified at a molecular level. The lesions are implicated circumstantially in premutational and mutational events which lead to altered metabolism or death of cells. Radiological health interest in ultraviolet radiation comes under Public Law 90-602 and is therefore relatively new from the standpoint of protection of the public. However, the U. S. Public Health Service pursued radiation protection measures, particularly for military personnel and shipyard workers, during World War II (15, 124). As an early step in fulfilling the Law, this paper has been prepared with the following purposes: (1) to identify the types of sources which may emit ultraviolet radiation, (2) to summarize the current knowledge of the biological effects of ultraviolet, (3) to indicate some gaps in knowledge about biological effects of ultraviolet, (4) to review applicable standards for ultraviolet exposure, (5) to discuss probable critical organs, and thereby (6) to imply, at least, the relative hazard of ultraviolet to the public. Liberal use has been made of reviews of biological effects and the reader is referred to them (52, 64, 93) for more nearly complete surveys of particular aspects of ultraviolet effects.

NATURE OF ULTRAVIOLET RADIATION

The ultraviolet region of the electromagnetic spectrum is intermediate in wavelength and frequency between the x-ray and visible regions. The limits of the ultraviolet portion are not clear-cut and may be considered to be electromagnetic radiation of wavelength between 40 and 4000 Å, or of frequency between 7.5×10^{16} and 7.5×10^{14} Hz. From a biological standpoint, the ultraviolet and x-ray spectra may be considered to meet at about 1000 Å (3×10^{15} Hz), where atoms and molecules can be ionized. The separation between ultraviolet and visible spectra may be considered to be about 3800 Å (about 7.9×10^{14} Hz), inasmuch as International Commission on Illumination defines visible radiation for practical purposes as the range of wavelengths between 3800 and 7800 Å. Biologically the ultraviolet spectrum may be divided into the extreme or vacuum region, from 1000 to 1900 Å, the range in which both air and water absorb the radiations. The region from 1900 to 3800 Å is divided into the far ultraviolet (1900-3000 Å) and near ultraviolet (3000-3800 Å) on the basis of absorption of solar ultraviolet below about 3000 Å by atmospheric ozone. The biological classification of ultraviolet regions will be used in this paper. The classification is not, however, universally accepted. Physicists may classify radiation in the region 4000-3000 Å as near ultraviolet, the region 3000-2000 Å as far ultraviolet, and 2000-40 Å as extreme ultraviolet. Wavelengths at which skin erythema is produced, i.e., 2800-3150 Å, is frequently referred to as middle ultraviolet by biologists. Photon energies range from about 3.26 eV at 3800 Å to 12.4 eV at 1000 Å wavelengths.

PRODUCTION OF ULTRAVIOLET RADIATION

Ultraviolet radiation is emitted whenever excited atoms make transitions from one state to another, concomitantly releasing photons with energies in the ultraviolet range. The two main methods used to excite atoms are the electrical arc, through a gas or vapor, and heat.

The most efficient and useful man-made sources of ultraviolet radiation are the arcs which occur when an electrical current is passed between electrodes separated by a gas or vapor. Arcs generally operate at currents in the order of amperes and voltage drops of less than 100 volts. Discharges between electrodes through a gas or vapor contained in a limiting envelope, such as quartz or glass, are enclosed arcs. Discharges between electrodes exposed to the atmosphere are termed open arcs.

The vapor pressure in enclosed arcs may be a few microns up to hundreds of atmospheres. In low pressure arcs, the spectrum is usually of the line or band type. Emission lines of mercury, a commonly used material for vaporization in enclosed arcs, are shown in Table 1. With increasing pressure, emission lines broaden non-uniformly and a continuous background appears and increases in brightness. Eventually the line character of the emission spectrum disappears. It should be noted that hydrogen-filled arc lamps emit a continuous spectrum down to about 1850 Å, even at low pressures. In low pressure arcs, gas molecule temperature may exceed 6000° K. The transition between low and high pressure occurs at pressures around 10 mm of mercury, when the electrons, ions, and gas molecules approach thermal equilibrium. High pressure arcs must be specially cooled.

Terrestrial incandescent bodies are weak and inefficient sources of ultraviolet. The production of total radiant energy from an incandescent source is proportional to the fourth power of the absolute temperature of the source. The spectral distribution moves toward shorter wavelengths as the absolute temperature increases.

TABLE 1

WAVELENGTHS OF MAJOR EMISSION LINES OF MERCURY ARCS BELOW 4000 Å a)

1850	2225	3022
1942	2378	3130 b)
	2399	3341
	2483	3656 b)
	2537	3906
	2652	3984
	2699	
	2753	
	2804	
	2894	
	2967	

a) (From reference 52)

b) Wavelength shown is the average of closely spaced lines. The 3130 wavelength is actually composed of 3125.6, 3131.56 and 3131.84 Å lines; the 3656 of 3650.15, 3654.83, 3662.87, and 3663.27 Å lines.

Table 2 shows the distribution of radiation in ultraviolet and visible ranges from standard General Electric lamps (41). Lamps operating at temperatures below 2500° K obviously emit very little ultraviolet. Open gas and oil flames are generally less than 2000° C. Oxyhydrogen and oxyacetylene flames are substantially hotter, so solids heating in them may radiate ultraviolet.

The sun is the hottest incandescent body with which we have long-term experience. The surface temperature is about 6000° K. Ultraviolet radiation from the sun is about 0.1 of the total radiation. In spite of this relatively low proportion, the quantity of ultraviolet radiation from the sun would be lethal to most terrestrial life, were it not screened out by the thin ozone layer in the earth's upper atmosphere (52).

The near ultraviolet transmittance to the earth's surface depends on the thickness of the air mass through which the radiation passes. The air mass thickness depends in part on the elevation of the sun above the horizon. Absorption and scattering figure prominently in attenuation of the radiation. Other factors affecting the radiation incidence at any given location include latitude, season, altitude and local atmospheric conditions. Solar flares cause relatively large fluctuations in near ultraviolet radiation. The Smithsonian Institution has performed daily measurements of solar radiation since the turn of the century (108).

Additional and detailed information can be obtained in (64) and (126). Information in Koller (64) formed the main basis for this section of this report.

TRANSMISSION OF ULTRAVIOLET RADIATION

Ultraviolet radiation produced in an enclosed incandescent or arc source may or may not pass through the enclosure, depending on the absorbing characteristics of the envelope. Crystalline or fused quartz is a common envelope material, and transmits ultraviolet wavelengths down to about 1850 Å. Window glass absorbs wavelengths below about 3000 Å. Plastics vary in their transmission characteristics, even among batches of mixtures of the same polymer.

The Corning Glass Company has developed several special glass filters, most of which transmit in the near ultraviolet. Band-pass filters may be constructed so that certain short regions of the ultraviolet spectrum can be effectively transmitted through aqueous solutions of cobaltous sulfate, nickelous sulfate and cupric sulfate in various combinations (56). Interference filters are useful band-pass devices. Baird Atomic has interference filters which pass relatively narrow bands of ultraviolet radiation.

TABLE 2

RADIATION DISTRIBUTION FROM INCANDESCENT LAMPS [a]

Bulb	Color Temperature, °K	Watts of Ultraviolet		% of Lamp Watts, total Ultraviolet	Total Visible Watts	% of Lamp Watts, total Visible
		2800-3200Å	3200-4000Å			
40W Standard	2560		0.027	0.068	2.65	6.6
100W Standard	2890		0.117	0.117	9.32	9.32
500W Standard	3000	0.005	0.88	0.176	54.84	11.
1000W Standard	3050	0.012	1.98	0.199	115.5	11.6
1000W Photoflood	3360	0.123	4.40	0.45	156.3	15.6

a) (From reference 41)

MODE OF ACTION OF ULTRAVIOLET RADIATION ON BIOLOGICAL TISSUES

Absorption of Ultraviolet Radiation

The most important absorbers of ultraviolet radiation in biological tissue are the organic molecules, not inorganic ones. The inorganic substances in tissue are probably not important for one or more of the following reasons (52):

1. Inorganic substances do not absorb ultraviolet energies of wavelengths above about 2000 Å.

2. Inorganic substances are relatively abundant in, and therefore not crucial to, the biological system.

3. Any produced photoproducts in inorganic substances are possibly normal constituents in the system.

Although direct action of ultraviolet radiation may be ignored for inorganic substances, their reactions with absorbing organic molecules may be biologically significant. Above about 2000-2200 Å, the important organic substrates are unsaturated. They contain intramolecular regions with alternating single and double bonds and form an absorbing unit, or chromophore, for an ultraviolet photon. The photon will initially excite the absorbing unit. The energy may then be transferred to a weak bond in a group adjacent to or within the absorbing unit. The weak bond may be broken. The absorption bands of some biologically common chromophores have been determined (92). For example, the -C=O absorbs around 2800 to 2900 Å; the -O-H absorbs below 2000 Å. The -COOH absorption is intermediate, around 2100 Å. Although most common conjugated structures absorb between 2000 and 3000 Å, some lie outside that range. For example, the -C=S, $-NO_2$, and anthracenic groups absorb between 3000 and 3800 Å. The absorption bands can be modified substantially by other parts of the molecule. Absorption spectra are available for a large number of organic compounds with one or more absorbing units (66). Such spectra can be modified by solvent and solvent pH (28). Variations in closely related molecules may be reflected in the spectra (86).

Large Molecules

Biological compounds with ultraviolet chromophores include amino acids (primarily the aromatic amino acids), purine and pyrimidine bases and other cyclic compounds, quinones, carotenoids, flavins and pterins. Proteins formed by amino acids and nucleic acids, formed by derivatives of purines and pyrimidines are the two organic types most common in cells. Relatively little research has been performed to determine the biological importance of ultraviolet irradiation of the compounds other than proteins and nucleic acids.

Peak absorption for proteins is about 2800 Å. In general, absorbency of a given protein in solution is similar to the sum of individual absorbencies of equivalent proportions of its constituent amino acids in solution, because of a relative lack of interaction among its amino acids. The chemical change in the polymerization of amino acids is the formation of the peptide linkage between the amino and the carboxyl groups. The peptide bond absorbs below 2400 Å.

For nucleic acids, polymerization of base derivatives is through sugar-phosphate linkages. The sugar and phosphate parts show essentially no absorption above 2100 Å; the bases absorb strongly in the region 2400-2900 Å. Nucleic acids have peak absorption at about 2600 Å. The total absorbency of nucleic acids is less than the sum of the absorbencies of equivalent proportions of its constituent bases in solution, because the bases interact in a polynucleotide chain. The polymerization to form polynucleotide chains is through sugar-phosphate linkages. On a per unit weight basis, nucleic acids absorb 10-20 times higher than proteins (52). Both proteins and nucleic acids absorb poorly above 3000 Å.

Cells

The problems in the measurement of ultraviolet absorption by living cells are substantial, and include (1) settling of cells, (2) the effect of cell suspensions to behave as a sieve for ultraviolet radiation because of the inhomogeneity of the suspension, (3) scattering of light by the cells, and (4) the size of the cells. The absorption cross section per cell has been estimated for Escherichia coli in the logarithmic phase of growth, when the dry weight composition is about 70 percent protein and 20 percent nucleic acid (95). In the region 2400-2800 Å, absorption due to nucleic acid is larger than absorption due to protein. Below 2300 Å, most of the absorption is due to peptide linkages in protein. In red blood cells, the ultraviolet absorption by porphyrins effectively masks absorption by other cell constituents (68).

Chiefly because of absorption by nucleic acids, most of far ultraviolet radiation becomes absorbed in 10 microns of average tissue. For cells larger than about 5 microns in diameter, therefore, penetration of ultraviolet radiation becomes an important problem. This problem has been ignored in some experimental work, with the result that conclusions drawn may be invalid.

The foregoing is concerned with the absorption of ultraviolet radiation in biological material. Absorption spectra essentially represent constructions of the fraction of the incident monochromatic energy which is absorbed in the material being examined at a series of wavelengths. The next part is concerned with the action of ultraviolet radiation in biological material, for which action spectra may be constructed.

Action of Ultraviolet Radiation

An action spectrum is the relative response of a system to different wavelengths. It may apply only under conditions used in obtaining it. Classically, an action spectrum is a plot of the reciprocal of dose required for a given effect versus wavelength (71). It is probably reliable for the set of conditions under which it is determined if the shapes of the dose-effect curves are similar at the wavelengths involved. Action spectra are usually obtained to determine the chromophore that is responsible for the observed effect. For the interpretation of action spectra, several assumptions are made (71,76):

1. The quantum yield is the same at all wavelengths.
2. The absorption spectrum of the absorbing material is the same in vivo and in vitro.
3. Absorption and scattering between the absorber of interest and the radiation impinging on the system is either negligible or constant at all wavelengths.
4. Absorption of incident radiation by the absorber is not total.
5. Reciprocity of time and dose rate holds under the conditions for which the action spectrum is determined.

Correspondence between absorption spectra for proteins and action spectra for spindle destruction in cells receiving ultraviolet irradiation of the cytoplasm indicates that the effects on spindle and cell division are due to a tyrosine-containing protein (13).

Action spectra for killing of Escherichia coli and Staphylococcus aureus show highest efficiency around 2650 Å (38) and therefore correspond more closely to the absorption spectrum of nucleic acid than to that of protein. The action spectrum for S. aureus suggests some protein involvement in the activation. A similar suggestion was made for Micrococcus radiodurans on the basis of action spectra for killing and delay in DNA synthesis (94). In general, action spectra for cell killing (37,38) mutagenesis (34,63; see 132 for review) and delay of cell division (29,30) have a maximum nearer 2600 Å than 2800 Å.

Killing of small cells by near ultraviolet radiation (3000-3800 Å) was observed in 1893 (123). No obvious maxima or minima are observed in the near ultraviolet region (72). The possibility that the absorbing site is in protein and/or nucleic acids is generally discounted, because both absorb very poorly at ultraviolet wavelengths above 3400 Å. The doses of near ultraviolet radiation required for killing are about 1000 times greater than doses required in the far ultraviolet (52). With near ultraviolet radiation, killing curves are strongly sigmoid and delay of bacterial cell division is pronounced, but mutations are not induced (46). Leakage of ions from cells is observed after non-lethal doses of near ultraviolet radiation (14). Action spectra for growth delay of bacteria have been obtained both in buffer (50) and in nutrient medium (84). Both peak at 3400 Å, a wavelength which is also the peak of the action spectrum for photoprotection. Photoprotection is another effect of near ultraviolet radiation, in which prior irradiation of certain cells decreases their subsequent sensitivity to far ultraviolet radiation (see 50 for review).

It is apparent, therefore, that the ultraviolet effect to kill bacteria, at least, depends primarily on absorption by nucleic acid in the far ultraviolet range and on some other material in the near ultraviolet range. In terms of setting human exposure standards, little research on the cellular effects of near ultraviolet radiation is available with mammalian or other large cells.

A number of effects of far ultraviolet radiation on DNA has been either observed or inferred (103), and includes DNA chain breaks (74,81), partial denaturation (74,90), cross linking between chains of a DNA molecule (1,75,100), linking between DNA and protein (1,106), hydration of certain pyrimidines (79,80,104), and formation of dimers of the cyclobutane type between adjacent pyrimidine bases (54,97,99,125,129). Pyrimidine dimers were discovered in ultraviolet-irradiated frozen solutions of thymine (5). Dimerization of other pyrimidines has been observed: cytosine (120,129), uracil (105,107,121), uracil-thymine (4,107,122), and cytosine-thymine (129). In DNA, the dimers of interest are those involving thymine and cytosine. Pyrimidine dimers are relatively stable to acid hydrolysis, and therefore have been readily separated from DNA. The acid hydrolysis deaminates the cytosine ring, so that uracil may be recognized in the hydrolysate. However, other photoproducts may be destroyed by acid hydrolysis (82). It is difficult to equate chemical alterations in DNA with the mutagenesis and cell killing that may be observed after irradiation. An attempt to correlate the two phenomena is complicated by cellular capacities for reducing the potential effects of the ultraviolet-induced changes. Such a correlation has been attempted (93), with the conclusions that (1) the available evidence supports the importance of pyrimidine dimer production in lethality of bacteria (see also 101), bacteriophage and transforming DNA, (2) pyrimidine dimer may or may not be solely responsible for lethal effects, but (3) no proof exists that any other ultraviolet-induced lesion can cause lethal effects, (4) repair of ultraviolet-damaged bacterial DNA takes place either by monomerization of dimers by enzyme plus light (photoreactivation,

see below) and enzymatic excision of dimers in the absence of light (dark repair, see below). With respect to mutagenesis and lethality, several problems for which solutions are required are listed: (1) the chemical nature of the photoreactivating enzyme, (2) the determination of whether the excision mechanism operates in viral DNA-directed repair of bacteriophage DNA, (3) the demonstration of DNA-repair replication in bacteria undergoing dark repair, (4) the chemical mechanism of enzymatic monomerization in the presence of light, (5) the nature and mechanisms of excision and repair-replication enzymes, (6) a complete list of lethal photoproducts in DNA and (7) the mechanisms of ultraviolet-induced mutagenesis.

Some information about pyrimidine dimers in non-bacterial cells is available. Cyclobutane-type dimers have been found in Paramecium aurelia (110,111), cultured Chinese hamster cells (109,117,119), mouse L cells (61,62) and human cells in vitro (19,20,88). Among mammalian cells tested, there exists a substantial variation in post-irradiation "repair" of the ultraviolet-induced lesions. Human cell lines tested (88) preferentially excise pyrimidine dimers from the DNA. Thymidine precursors are inserted into presumably degraded regions of DNA in irradiated HeLa cells with 5-bromouracil-substituted DNA (21). Primary fibroblast cultures from skin biopsies of persons with the rare hereditary disease, xeroderma pigmentosum, on the other hand, do not undergo replication after ultraviolet irradiation (20).

What is meant by "repair" of ultraviolet-induced pyrimidine dimers? One or more of several processes may operate to remove, physically or otherwise, dimers. The dimerization of adjacent thymines is a reversible reaction, so that the steady state value between dimers and monomers depends on wavelengths (31,55). Around 2800 Å, the steady state favors dimer formation. Around 2400 Å, the steady state is in favor of monomers. Therefore a dimer may be split by short wavelength irradiation (101). Dimers are also split when dimer-containing DNA is irradiated at 3650 Å in the presence of photoreactivating enzyme (130). Photoreactivation, a light-triggered phenomenon affecting recovery of cells from irradiation, was first observed in 1949 (59). The first clue that it is a photoenzymatic process came in 1957 (43; see 93 for review). Photoreactivating enzyme has been found widely in nature, including many organisms whose habitats are shielded from ultraviolet radiation (24). The production of the enzyme has been studied as a function of cell growth (9) and in amphibian tissues (23). Evidence also exists for an indirect photoreactivating mechanism, similar to photoprotection (53,65). Other post-irradiation environmental conditions affect survival of organisms (47,89). These environmental conditions do not require light. Dark recovery phenomena may have varied mechanisms. One which has received attention is the excision of an oligonucleotide around and including the dimer and

the resynthesis of the piece of DNA (11,83,98). Excision-resynthesis repair has been studied in mammalian cells (19,20,21,48,61,87,88,109,118, 119). Genetic control of abilities to remove dimers has been described in bacteria (49,127,128; see 96 for review). One report (20) relates the inability to excise dimers to a hereditary human disease, xeroderma pigmentosum. Persons with this rare condition are quite sensitive to ultraviolet and sunlight, and have a pronounced tendency to develop skin tumors.

The preceding discussion is related directly to the formation of dimers in DNA. Some evidence is available that photoreactivable damage of lesions in RNA may contribute to mutation in small cells (see 51 for review).

In large cells effects of ultraviolet irradiation are noted which may not be related to the formation of dimers. Far ultraviolet radiation produces genetic and chromosome damage. Studies of genetic mutation from ultraviolet radiation between 1928, when x rays were shown to be mutagenic, and 1930, yielded negative results. First ultraviolet-induced mutations were obtained in Drosophila (2,3,40,85). The Drosophila studies excluded translocations affecting the II, III and IV chromosomes, and minute rearrangements, as mutagenic events after ultraviolet irradiation. They also showed that mutagenesis occurred at wavelengths below 3200 Å. Dose fractionation did not affect the frequency of mutations or degree of sterility in the flies (115). Other experiments with ultraviolet mutagenesis in maize were performed by Stadler and summarized in Lea (69). In general, his results may be summarized as follows: (1) the ratio of the number of induced gene mutations that lead to a visible change to induced chromosome deficiencies is higher with ultraviolet radiation than with x rays and (2) ultraviolet-induced deficiencies appear to be located terminally in the linkage groups. The early work with directly detected chromosome aberrations in Tradescantia pollen showed that the most frequent aberration was the terminal deletion (112-114). Isochromatid deletions and chromatid translocations were no more frequent in irradiated pollen than in unirradiated pollen. The frequency of terminal deletions increased linearly with dose (113). The action spectrum for chromosome aberrations in Tradescantia pollen is of the nucleic acid type (60).

On the other hand, all types of cytologically detectable chromatid and chromosome aberrations were observed in Chinese hamster cells in vitro (18). They are induced throughout the cell cycle, so the transition from the chromosome type to the chromatid type during DNA synthesis of x-irradiated cells is not observed. They are not photoreactivable. The frequency of aberrations is wavelength dependent, with a maximum in the region 2400-2800 Å. Incubation of cells in a halogenated analog of thymidine prior to irradiation increases the frequency of aberrations at a given wavelength. Demolition of chromosomes is pronounced after 2800 Å irradiation. Chromosomal demolition is also observed after 2650 Å irradiation followed by puromycin treatment of the cells.

Delay of cells in their progression through the cell cycle is another general ultraviolet-induced phenomenon (10,22,32,33,78,116,117,131; see 16 and 42 for reviews). Depending on the cell type used, maximum retardation may occur in G1, S or G2. Incorporation of tritiated thymidine into DNA has been demonstrated to be concomitant with mitotic delay during prophase and may even follow ultraviolet doses at which delay is not detected (70). Prophase delay appears to be a general phenomenon in x-irradiated cells (17). The action spectrum for mitotic delay has at least a nucleic acid-type component, with some reports of a broad effective range embracing the nucleic acid and protein wavelengths (117). Ultraviolet microbeam irradiation of a nucleolus in grasshopper neuroblasts permanently stops the cells from division (39). Other microbeam effects on cell constituents are reviewed by Zirkle and Uretz (133).

Time lapse and electron microscopic studies of ultraviolet-irradiated cells revealed a variety of changes in virtually every cell constituent (see 42 and 78 for reviews). Zeiosis (cell blebbing), mitotic delay, division failure with the production of giant cells and cell necrosis were documented by cinemicrography. Cellular membranes became thicker and more electron dense; mitochondria swelled and became empty, apparently single membrane bound ghosts. Some of these changes are documented in a variety of material (see 16 for review).

Ultraviolet irradiation can cause skin erythema. This subject will be discussed in a later section.

Induction of skin cancer in mice by ultraviolet radiation was first reported in 1928 (35). Studies in this area stopped about 1950, and are reviewed by Blum (7). The points of interest in the review are 1) carcinogenic wavelengths are below 3200 Å; 2) repeated exposures are necessary to induce tumors experimentally, with the proportion of tumor types varying with the frequency of exposure; 3) among caucasians the cancer occurs predominantly on the face; 4) attempts to relate distribution of skin cancer cases to incidence of sunlight are equivocal; 5) the suspected relationship between cancer incidence and complexion of caucasians is equivocal, and 6) a clear north-south distribution of cancer incidence is indicated for both sexes of caucasians, with greater incidence in the South.

PHYSICAL FACTORS INFLUENCING TISSUE DAMAGE

In the intact animal incident ultraviolet radiation does not penetrate through the skin. Below 2900 Å, absorption in humans is entirely in the epidermis (52). Between 2900 and 3200 Å, less than 10 percent of the incident ultraviolet radiation reaches the dermis. Above 4000 Å over 50 percent of the incident light reaches the dermis (36). Internal organs are therefore not considered liable to ultraviolet-induced damage.

The ultraviolet radiation from any given source depends on the source and on the absorbing material around the source. For example, a clear quartz envelope in place of the phosphor-coated glass of an ordinary fluorescent lamp would convert that lamp into a powerful germicidal lamp emitting chiefly 2537 Å radiation.

Any shielding between the ultraviolet source and the intact animal either reduces or eliminates ultraviolet radiation. With few exceptions, media which transmit visible light may be suspected of transmitting ultraviolet. A list of some commonly-used ultraviolet transmitting materials is given in (52) in Appendix A.

WHOLE BODY EXPOSURE

"Whole body" exposure of large numbers of humans to ultraviolet radiation is not likely. Common articles of clothing are effectively opaque to ultraviolet radiation. Inasmuch as ultraviolet radiation is absorbed in skin, the depth dose considerations of whole body exposures to penetrating types of radiations do not apply to the ultraviolet "whole body" exposure situations.

A report at the American Industrial Hygiene Conference in 1968 (91) revealed no significant clinical or subjective symptoms from 3650 Å irradiation at 20-210 $\mu W/cm^2$ of a small group of night club workers whose working situations may approach whole-body exposure conditions. The wavelength was contaminated by wavelengths below 3200 Å to the extent of about 1-4 percent of the total radiation.

CRITICAL ORGANS

The critical organs for ultraviolet radiation are the skin, including lips, and the eye (52).

Skin

The skin is the main absorber of ultraviolet radiation and reacts by erythema, tanning, and pigment darkening (6).

The erythema is a reddening of the skin as a result of dilation and engorgement of minute blood vessels in the dermis. An hour's exposure to summer midday bright sun may produce erythema. An hour or more may lapse between exposure and detectable reddening. The erythema may be accompanied by slight swelling of the exposed region. Severe exposures result in blistering and desquamation. Relative exposure time for degree of erythema is shown in Table 3 (64).

TABLE 3

DEGREE OF ERYTHEMA PRODUCED BY EXPOSURE TO SUMMER NOONDAY SUN [a)]

Relative Duration of Exposure	Degree of Erythema
1	Minimum perceptible erythema (reddening disappears in 24 hours)
2.5	Vivid reddening followed by moderate tan
5	Painful burn
10	Blistering

a) (From reference 64)

Pre-erythemal histological changes in exposed skin are not evident (44,57,58,77). About the time erythema is detected, intracellular edema and migration of leukocytes into the irradiated region begin.

The action spectrum for production of erythema peaks at about 2970 Å, and drops rapidly to essentially zero at 3200 Å. A minimum is reached around 2800 Å, and a second maximum is reached below 2500 Å (73). Erythema that is "minimally perceptible" (disappears in 24 hours after exposure) is produced in untanned skin by 250,000 ergs/cm^2 of 2967 Å radiation (64).

The latent period for erythema is shorter after exposure to the sun than after exposure to a mercury arc (67). The erythema reaches a maximum more slowly after mercury arc exposures than after exposures to sun. At the long wavelengths the degree of erythema increases more rapidly with increasing dose than it increases after exposure to short wavelengths.

A measure of ultraviolet dosage is based on erythema, and is termed the erythemal unit. The erythemal unit (EU) has been defined as 10μW of homogeneous radiation of wavelength 2967 Å (27).

The use of EU requires reciprocity for validity. Other factors affect the accuracy of the estimate obtained by the EU. Substantial variations in the amount of a given radiant energy occur from individual to individual, and between different parts of one individual. It is difficult, for example, to produce erythema on the palms of the hand or the soles of the feet. Skin, when moist, is more susceptible to erythema induction than when dry. The lips, with thin, frequently wet, skin, are therefore particularly susceptible (52).

Erythema usually appears to fade into suntan. The relationship between the two is not as direct. Suntan is the result, first of all, of the change in distribution of melanin pigment in the epidermis, and, secondly, an increase in the quantity of melanin in the epidermis. Pigment migrates toward the skin's outer surface from the basal cell layer about 24 hours after exposure to ultraviolet radiation (57). A third phase of tanning is the darkening of the epidermally situated melanin. The action spectrum peak is around 3400-3500 Å for pigment darkening (45). The relationship between erythema and skin cancer, if any, is obscure. It is difficult to avoid a causal connection, however, between sunlight and induction of skin cancer (7).

Eye

Ultraviolet exposure of the eye may result in painful corneal burn and blindness. During World War II eye damage was substantial among unprotected shipyard workers who were exposed to welding arcs and this provided a basis for USPHS interest (15). To give some estimate of the radiation required, Dr. D. Q. Brown has made measurements of the power density emanating from a source under conditions which led to one painful case of corneal injury. Based on the accident, he estimated that 10 microwatts/cm^2 from a germicidal lamp (principal radiation is at 2537 Å) for 20 minutes could produce the corneal injury, even if the person did not look directly at the source during exposure (12).

Ultraviolet radiation incident on the eye is absorbed successively by the cornea, the aqueous humor, the lens and the vitreous humor. According to Koller (64), relative absorption is greatest in the lens, next in the cornea, next in the vitreous humor, and last in the aqueous humor. Ultraviolet below 3000 Å is absorbed essentially entirely in the cornea and aqueous humor. Very little penetrates as far as the lens. The lens transmits approximately 13 percent of incident radiation at 4050 Å, but only about 0.15 percent of incident radiation at 3650 Å (8). In the intact eye, ultraviolet radiation does not reach the retina. It is obvious, however, that removal of portions of the eyes, such as cornea in cataract operations or the lens, decreases the ultraviolet absorbing media.

CUMULATIVE EFFECTS

The major observation of cumulative effects of ultraviolet is concerned with the production of skin cancer. As previously noted, repeated exposures are necessary to induce malignancy (7).

APPLICABLE STANDARDS FOR ULTRAVIOLET EXPOSURE OF HUMANS

The Council on Physical Medicine of the American Medical Association has recommended a maximum level of exposure to germicidal ultraviolet lamps, with peak emission at 2537 Å (26). The basis for the recommendations is the observation that exposure to 36 μW/cm^2 of 2537 Å radiation produces erythema in about 15 minutes. With the assumptions that the reciprocity law is applicable in situations of low intensities and long exposures, exposure rates are set. The exposure rate to the total 2537 Å radiation, both direct and reflected, should not exceed 0.5 μW/cm^2 for persons exposed for 7 hours or less. For persons continuously exposed

(24 hours a day) the total 2537 Å radiation exposure rate should not exceed 0.10 $\mu W/cm^2$. The Council furthermore accepts germicidal lamps which produce virtually no ozone (the type "L" lamp). This recommendation updates an earlier one (27) from the Council on Physical Therapy.

The Council on Physical Medicine has also considered hazards to eyes from use of "black light" ultraviolet (3650-3660 Å) (25). The wavelength is used to detect ringworm. The recommendations include 1) suitable housing for the lamps, and 2) goggles for prolonged usage or for usage of high powered lamps. The goggle material should completely absorb the 3660 Å radiation, and at least 90 percent of the 4055 Å line, but transmit not less than 85 percent of blue-green fluorescence (5200-5800 Å). The material must not itself fluoresce. The Council points out that the black light region from direct sunlight is not sufficiently intense to cause eye fluorescence and fatigue, so the recommendation is not intended as an indirect endorsement of sunglasses.

Other standards for ultraviolet radiation from other agencies are summarized in an annotated bibliography (102).

SUMMARY

Ultraviolet radiation is produced by arcs and incandescent sources operating at high temperatures. The envelope of closed sources may filter out most of the ultraviolet radiation produced. Of the transmitted ultraviolet, two portions of the spectrum are of public health interest. Wavelengths between 1900 and 3000 Å (far ultraviolet) are mutagenic, and may be lethal to cells. Wavelengths above about 3000 Å (near ultraviolet) appear not to be mutagenic, and are lethal at doses which are very high in comparison with lethal doses in the 1900-3000 Å range. However, skin cancer may result from repeated near ultraviolet exposure. Penetration of ultraviolet beyond the skin of mammals is negligible. Wavelengths below about 1900 Å (vacuum ultraviolet) are absorbed by air and water, so exposure of biological tissue must be performed in vacuo.

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References to commercial firms and products are not intended to convey endorsement by the U. S. Public Health Service.

REFERENCES

1. Alexander, P. and H. Moroson. 1962. Cross-linking of deoxyribonucleic acid strands and its reversal by photoreactivating enzyme. Biochem. Biophys. Acta 12: 508-514.

2. Altenberg, E. 1930. The effect of ultraviolet radiation on mutation. Anat. Record 47: 383.

3. Altenberg, E. 1931. Genetic effects of ultraviolet radiation. Anat. Record 51: 108-109.

4. Beukers, R. and W. Berends. 1960. Isolation and identification of the irradiation product of thymine. Biochem. Biophys. Acta 41: 550-551.

5. Beukers, R. J. Ylotra and W. Berends. 1958. The effect of ultraviolet light on some components of the nucleic acids. Rec. Trav. Chim. Pays-Bas 77: 729-732.

6. Blum, H. F. 1955. Sunburn, p. 487-528. In Hollaender, A. (ed.), Radiation Biology, Vol. 2 McGraw-Hill, New York.

7. Blum, H. F. 1955. Ultraviolet radiation and cancer, p. 529-559. In Hollaender, A. (ed.), Radiation Biology, Vol. 2. McGraw-Hill, New York.

8. Boettner, E. A. 1967. Spectral transmission of the eye. AD 663246. (National Bureau of Standards, Gaithersburg, Maryland) 37 p.

9. Boling, M. E. and J. K. Setlow. 1967. Photoreactivating enzyme in logarithmic-phase and stationary-phase yeast cells. Biochem. Biophys. Acta 145: 502-505.

10. Bootsma, D. and R. M. Humphrey. 1968. The progression of mammalian cells through the division cycle following ultraviolet irradiation. Mutation Res. 5: 289-298.

11. Boyce, R. P. and P. Howard-Flanders. 1964. Release of ultraviolet light-induced thymine dimers from DNA in E. coli K-12. Proc. Natl. Acad. Sci. J. S. 51: 226-231.

12. Brown, D. Q. Personal communication.

13. Brown, D. Q. and R. E. Zirkle. 1967. Action spectra for mitotic spindle destruction and anaphase delay following irradiation of the cytoplasm with an ultraviolet microbeam. Photochem. Photobiol. 6: 817-828.

14. Bruce, A. K. 1958. Response of potassium retentivity and survival of yeast to far-ultraviolet, near-ultraviolet and visible, and x-radiation. J. Gen. Physiol. 41: 693-702.

15. Carlson, J. G. Personal communication.

16. Carlson, J. G. 1954. Immediate effects on division, morphology, and viability of the cell, p. 763-824. In Hollaender, A. (ed.), Radiation Biology, Vol. 1 McGraw-Hill, New York.

17. Carlson, J. G. 1968. Prophase sensitivity of mitosis to x rays in certain invertebrate and vertebrate cells in vitro. Book of Abstracts, 3rd Internatl. Congress Radiat. Res., Cortina d'Ampezzo, Italy, p. 48.

18. Chu, E. H. Y. 1965. Effects of ultraviolet radiation on mammalian cells. I. Induction of chromosome aberrations. Mutation Res. 2: 75-94.

19. Cleaver, J. E. 1967. The relationship between the rate of DNA synthesis and its inhibition by ultraviolet light in mammalian cells. Radiat. Res. 30: 795-810.

20. Cleaver, J. E. 1968. Defective repair replication of DNA in xeroderma pigmentosum. Nature 218: 652-656.

21. Cleaver, J. E. 1968. Repair replication and degradation of bromouracil-substituted DNA in mammalian cells after irradiation with ultraviolet light. Biophys. J. 8: 775-791.

22. Cook, J. S. 1968. On the role of DNA in the ultraviolet-sensitivity of cell division in sand dollar zygotes. Exptl. Cell Res. 50: 627-638.

23. Cook, J. S. and J. R. McGrath. 1967. Photoreactivating-enzyme activity in metazoa. Proc. Natl. Acad. Sci. U. S. 58: 1359-1365.

24. Cook, J. S. and J. K. Setlow. 1966. Photoreactivating enzyme in the sea urchin egg. Biochem. Biophys. Res. Comm. 24: 285-289.

25. Council on Physical Medicine. 1946. Eye discomfort caused by improperly shielded black light ultraviolet lamps. J. Am. Med. Assn. 131: 287.

26. Council on Physical Medicine. 1948. Acceptance of ultraviolet lamps for disinfecting purposes. J. Am. Med. Assn. 137: 1600-1603.

27. Council on Physical Therapy. 1943. Acceptance of ultraviolet lamps for disinfecting purposes. J. Am. Med. Assn. 122: 503-505.

28. Daglish, C., N. Baxter and F. Wokes. 1948. The spectroscopy of riboflavine. Quart. J. Pharmacol. 21: 344-355.

29. Deering, R. A. 1958. Studies on division inhibition and filament formation of Escherichia coli by ultraviolet light. J. Bact. 76: 123-130.

30. Deering, R. A. and R. B. Setlow. 1957. Inhibition of cell division of Escherichia coli by low doses of ultraviolet light. Science 126: 397-398.

31. Deering, R. A. and R. B. Setlow. 1963. Effects of ultraviolet light on thymidine dinucleotide and polynucleotide. Biochem. Biophys. Acta 68: 526.

32. Devi, V. R., E. Guttes and S. Guttes. 1968. Effects of ultraviolet light on mitosis in Physarum polycephalum. Exptl. Cell Res. 50: 589-598.

33. Domon, M. and A. M. Rauth. 1968. Ultraviolet irradiation of mouse L cells: Effects on DNA synthesis and progression through the cell cycle. Radiat. Res. 35: 350-368.

34. Emmons, C. W. and A. Hollaender. 1939. The action of ultraviolet radiation on dermatophytes. II. Mutations induced in cultures of dermatophytes by exposure of spores to monochromatic ultraviolet radiation. Am. J. Bot. 26: 467-475.

35. Findlay, G. M. 1928. Ultraviolet light and skin cancer. Lancet 215: 1070-1073.

36. Fischer, E. and S. Solomon. 1959. Ultraviolet radiation. E. Licht, New Haven, Connecticut.

37. Gates, F. L. 1928. On nuclear derivatives and the lethal action of ultraviolet light. Science 68: 479-480.

38. Gates, F. L. 1930. A study of the bactericidal action of ultraviolet light. III. The absorption of ultraviolet light by bacteria. J. Gen. Physiol. 14: 31-42.

39. Gaulden, M. E. and R. P. Perry. 1958. Influence of the nucleolus on mitosis as revealed by ultraviolet microbeam irradiation. Proc. Natl. Acad. Sci., U. S. 44: 553-559.

40. Geigy, R. 1931. Action de l'ultraviolet sur le pole germinal dans l'oeuf de Drosophila melanogaster. Rev. suisse zool. 38:187.

41. General Electric Co., Lamp Bulletin LD-1, 1956.

42. Giese, A. C. 1964. Studies on ultraviolet radiation action upon animal cells, p. 203-245. In Giese, A. C. (ed.), Photophysiology, Vol. 2. Academic Press, New York.

43. Goodgal, S. H., C. S. Rupert and R. M. Herriott. 1957. Photoreactivation of Hemophilus influenzae transforming factor for streptomycin resistance by an extract of Escherichia coli B. In McElroy, W. D. and B. Glass (eds.), The chemical basis of heredity. Johns Hopkins Press, Baltimore.

44. Hamperl, H., U. Henschke and R. Schulze. 1939. Vergleich der Hautreaktionen beim Bestrahlungserythem und bei der direkten Pigmentierung. Virchow's Arch. path. Anat. u. Physiol. 304: 19-33.

45. Henschke, U. and R. Schulze. 1939. Untersuchungen zum Problem der Ultraviolett-Dosimetrie. III. Ueber Pigmentierung durch langwelliges Ultraviolett. Strahlentherapie 64: 14-42.

46. Hollaender, A. 1943. Effect of long ultraviolet and short visible radiation (3500-4900Å) on Escherichia coli. J. Bacteriol. 46: 531-541.

47. Hollaender, A. and W. D. Claus. 1937. An experimental study of the problem of mitogenetic radiation. Bull. Natl. Res. Council 100. Natl. Acad. Sci. U. S., Washington, D. C.

48. Horikawa, M., O. Nikaids and T. Sugahara. 1968. Dark reactivation of damage induced by ultraviolet light in mammalian cells in vitro. Nature 218: 489-491.

49. Howard-Flanders, P. and R. P. Boyce. 1966. DNA repair and genetic recombination: Studies on mutants of Escherichia coli defective in these processes. Radiat. Res. (Suppl. 6): 156-181.

50. Jagger, J. 1964. Photoprotection from far ultraviolet effects in cells, p. 584-601. In Duchesne, J. (ed.), Advances in chemical physics, Vol. 7. Interscience Publishers, Inc., New York.

51. Jagger, J. 1965. Photochemistry of nucleic acids and its biological implications, p. 59-80. In Bowen, E. J. (ed.), Rapporteur's Report, Recent progress in photobiology. Blackwell Scientific Publications, Oxford.

52. Jagger, J. 1967. Introduction to research in ultraviolet photobiology. Prentice-Hall, Englewood Cliffs, N. J., 164 p.

53. Jagger, J. and R. S. Stafford. 1965. Evidence for two mechanisms of photoreactivation in Escherichia coli B. Biophys. J. 5: 75-88.

54. Johns, H. E., M. L. Pearson, J. C. LeBlanc, and C. W. Helleiner. 1964. The ultraviolet photochemistry of thymidylyl-(3'→5')-thymidine. J. Mol. Biol. 9: 503-524.

55. Johns, H. E., S. A. Rapaport and M. Delbrueck. 1962. Photochemistry of thymine dimers. J. Mol. Biol. 4: 104.

56. Kasha, M. 1948. Transmission filters for the ultraviolet. J. Opt. Soc. Am. 38: 929-934.

57. Keller, P. 1924. Ueber die Wirkung des ultravioletten Lichtes auf die Haut unter besonderer Beruecksichtigung der Dosierung. III. Histologie der Lichtzuendung. Strahlentherapie 16: 537-553.

58. Keller, P. 1924. Ueber die Wirkung des ultravioletten Lichtes auf die Haut unter besonderer Beruecksichtigung der Dosierung. IV. Lichtgewoehnung und Pigmentierung. Strahlentherapie 16: 824-835.

59. Kelner, A. 1949. Effect of visible light on the recovery of Streptomyces griseus conidia from ultraviolet irradiation injury. Proc. Natl. Acad. Sci. U. S. 35: 73-79.

60. Kirby-Smith, J. S. and D. L. Craig. 1957. The induction of chromosome aberrations in Tradescantia by ultraviolet radiation. Genetics 42: 176-187.

61. Klimek, M. 1965. Formation but no excision of thymine dimers in mammalian cells after UV-irradiation. Neoplasma 12: 459-460.

62. Klimek, M. 1966. Thymine dimerization in L-strain mammalian cells after irradiation with ultraviolet light and the search for repair mechanisms. Photochem. Photobiol. 5: 603.

63. Knapp, E., A. Reuss, O. Risse and H. Schreiber. 1939. Quantitative Analyse der mutationsausloesenden Wirkung monochromatischen UV-Lichtes. Naturwiss. 27: 304.

64. Koller, L. R. 1965. Ultraviolet radiation, 2d ed. John Wiley & Sons, New York, 312 p.

65. Kondo, S. and J. Jagger. 1966. Action spectra for photoreactivation of mutation to prototrophy in strains of Escherichia coli possessing and lacking photoreactivating enzyme activity. Photochem. Photobiol. 5: 189-200.

66. Lang, L., (ed.). 1959. Absorption spectra in the ultraviolet and visible region, Vol. 1; Vol. 2, 1961; Vol. 3, 1962; Vol. 4, 1963; Vol. 5, 1965. Publishing House, Hungarian Acad. Sci., Budapest (Academic Press, New York).

67. Langen, D. 1938. Experimentelle Studien ueber die Erythembildung der Sonnenund Himmilsstrahlung. Strahlentherapie 63: 142-170.

68. Latimer, P. and C. A. H. Eubanks. 1962. Absorption spectrophotometry of turbid suspension: A method of correcting for large systematic distortions. Arch. Biochem. Biophys. 98: 274-285.

69. Lea, D. E. 1955. Actions of radiations on living cells, 2d ed. Cambridge University Press, Cambridge, 416 p.

70. Leach, W. M. and J. G. Carlson. 1967. Ultraviolet-induced incorporation of tritiated thymidine into Chortophage neurcblasts during prophase. J. Cell Biol. 35: 77A.

71. Loofbourow, J. R. 1948. Effects of ultraviolet radiation on cells. Growth 12 (Suppl.): 75-149.

72. Luckiesh, M. 1946. Applications of germicidal, erythemal and infrared energy. Van Nostrand, Princeton, New Jersey.

73. Luckiesh, M., L. L. Holladay and A. H. Taylor. 1930. Reaction of untanned human skin to ultraviolet radiation. J. Opt. Soc. Am. 20: 423-432.

74. Marmur, J., W. F. Anderson, L. Matthews, K. Berns, E. Gajewska, D. Lane and P. Doty. 1961. The effects of ultraviolet light on the biological and physical chemical properties of deoxyribonucleic acids. J. Cell Comp. Physiol. 58 (Suppl. 1): 33-56.

75. Marmur, J. and L. Grossman. 1961. Ultraviolet light induced linking of deoxyribonucleic acid strands and its reversal by photoreactivating enzyme. Proc. Natl. Acad. Sci. U. S. 47: 778.

76. McLaren, A. D. and D. Shugar. 1964. Photochemistry of proteins and nucleic acids. Pergamon Press, Long Island City, New York.

77. Miescher, G. 1930. Das Problem des Lichtschutzes und Lichtgewoehnung. Strahlentherapie 35: 403-443.

78. Montgomery, P. O'B. and R. C. Reynords. 1964. Cellular and subcellular responses to ultraviolet radiation. Lab. Invest. 13: 1243-1253.

79. Moore, A. M. 1958. Ultraviolet irradiation of pyrimidine derivatives. II. Note on the synthesis of the product of reversible photolysis of uracil. Can. J. Chem. 36: 281-283.

80. Moore, A. M. and C. H. Thomson. 1957. Ultraviolet irradiation of pyrimidine derivatives. I. 1, 3-Dimethyluracil. Can. J. Chem. 35: 163-169.

81. Moroson, H. and P. Alexander. 1961. Changes produced by ultraviolet light in the presence and in the absence of oxygen on the physical chemical properties of deoxyribonucleic acid. Radiat. Res. 14: 29-49.

82. Pearson, M. L., F. P. Ottensmeyer and H. E. Johns. 1965. Properties of an unusual photoproduct of U. V. irradiated thymidylyl-thymidine. Photochem. Photobiol. 4: 739.

83. Pettijohn, D. and P. Hanawalt. 1964. Evidence for repair-replication of ultraviolet damaged DNA in bacteria. J. Mol. Biol. 9: 395-410.

84. Phillips, S. L., S. Person and J. Jagger. 1967. Division delay induced in Escherichia coli by near ultraviolet radiation. J. Bacteriol. 94: 165.

85. Promptov, A. N. 1932. The effect of short ultraviolet rays on the appearance of hereditary variations in Drosophila melanogaster. J. Genetics 26: 59-74.

86. Pruckner, F. and A. Stern. 1936. Ueber die Lichtabsorption der Porphysine. IX. (Ultraviolet Absorption I). Z. physik. Chem. A177: 387-397.

87. Rauth, A. M. 1967. Evidence for dark-reactivation of ultraviolet light damage induced by ultraviolet light in mammalian cells in vitro. Nature 218: 489-491.

88. Regan, J. D., J. E. Trosko and W. L. Carrier. 1968. Evidence for excision of ultraviolet-induced pyrimidine dimers from the DNA of human cells in vitro. Biophys. J. 8: 319-325.

89. Roberts, R. B. and E. Aldous. 1949. Recovery from ultraviolet-irradiation in Escherichia coli. J. Bacteriol. 57: 363-375.

90. Sauerbier, W. 1960. Effects of ultraviolet light on hydrogen bonds in deoxyribonucleic acid of phage T1. Nature 188: 329-330.

91. Schall, E. L., C. H. Powell, G. A. Gellin and M. M. Key. 1968. Hazards of go-go dancing--the bare facts. Am. Ind. Hygiene Conference, St. Louis, Mo.

92. Scott, J. F. 1955. Ultraviolet absorption spectroscopy, p. 131-203. In Oster, G. and A. W. Pollister (eds.), Physical techniques in biological research, Vol. 1. Academic Press, New York.

93. Setlow, J. K. 1966. The molecular basis of biological effects of ultraviolet radiation and photoreactivation, p. 195-248. In Ebert, M. and A. Howard (eds.), Current topics in radiation research, Vol. 2. North-Holland Publishing Co., Amsterdam.

94. Setlow, J. K. and M. E. Boling. 1965. The resistance of Micrococcus radiodurans to ultraviolet radiation. II. Action spectra for killing, delay in DNA synthesis and thymine dimerization. Biochem. Biophys. Acta 108: 259-265.

95. Setlow, R. B. 1960. Ultraviolet wavelength dependent effects on proteins and nucleic acids. Radiat. Res. (Suppl. 2): 276-289.

96. Setlow, R. B. 1968. The photochemistry, photobiology, and repair of polynucleotides, p. 257-295. In Davidson, J. N. and W. E. Cohn (eds.), Progress in nucleic acid research and molecular biology, Vol. 8. Academic Press, New York.

97. Setlow, R. B. and W. L. Carrier. 1963. Identification of ultraviolet-induced thymine dimers in DNA by absorbence measurements. Photochem. Photobiol. 2: 49-58.

98. Setlow, R. B. 1964. The disappearance of thymine dimers from DNA: An error-correcting mechanism. Proc. Natl. Acad. Sci. U. S. 51: 226-231.

99. Setlow, R. B., W. L. Carrier and F. J. Bollum. 1965. Pyrimidine dimers in UV-irradiated poly dI:dC. Proc. Natl. Acad. Sci. U. S. 53: 1111-1118.

100. Setlow, R. and B. Doyle. 1953. The effect of light of wavelength 2,537Å on proteins and nucleic acid at low temperatures. Biochem. Biophys. Acta 12: 508-514.

101. Setlow, R. B. and J. K. Setlow. 1962. Evidence that ultraviolet-induced thymine dimers in DNA cause biological damage. Proc. Natl. Acad. Sci. U. S. 48: 1250-1257.

102. Setter, L. R., D. R. Snavely, D. L. Solem and R. F. Van Wye. 1969. Regulations, standards, and guides for microwaves, ultraviolet radiation, and radiation from lasers and television receivers--an annotated bibliography. PHS No. 999-RH-35 (Bureau of Radiological Health, Rockville, Maryland) 77 p.

103. Shugar, D. 1962. Primary effects of ultraviolet radiation on nucleic acids. Abhandl. Deut. Acad. Wissensch. Berlin 1: 72-83.

104. Sinsheimer, R. L. and R. Hastings. 1949. A reversible photochemical alteration of uracil and uridine. Science 110: 525-526.

105. Smietanowska, A. and D. Shugar. 1961. Photochemistry of model oligo- and polynucleotides. V. Properties of photodimers of uracil and thymine. Bull. Acad. Polon. Sci. 9: 375-380.

106. Smith, K. C. 1962. Dose dependent decrease in extractability of DNA from bacteria following irradiation with ultraviolet light or with visible light plus dye. Biochem. Biophys. Res. Comm. 8: 157-163.

107. Smith, K. C. 1963. Photochemical of thymine, uracil, uridine, cytosine and bromouracil in frozen solution and in dried films. Photochem. Photobiol. 2: 503-518.

108. Smithsonian Institution, 1954. Smithsonian physical tables, 9th ed. The Smithsonian Institution, Washington, D. C.

109. Steward, D. L. and R. M. Humphrey. 1966. Induction of thymine dimers in synchronized populations of Chinese hamster cells. Nature 212: 298-300.

110. Sutherland, B. M., W. L. Carrier and R. B. Setlow. 1967. Photoreactivation in vivo of pyrimidine dimers in paramecium DNA. Science 158: 1699-1700.

111. Sutherland, B. M., W. L. Carrier and R. B. Setlow. 1968. Pyrimidine dimers in the DNA of Paramecium aurelia. Biophys. J. 8: 490-499.

112. Swanson, C. P. 1940. A comparison of chromosomal aberrations induced by x ray and ultraviolet radiation. Proc. Natl. Acad. Sci. U. S. 26: 366-373.

113. Swanson, C. P. 1942. The effects of ultraviolet and x-ray treatment on the pollen tube chromosomes of Tradescantia. Genetics 27: 491-503.

114. Swanson, C. P. 1943. Differential sensitivity of prophase pollen tube chromosomes to x rays and ultraviolet radiation. J. Gen. Physiol. 26: 485-494.

115. Swanson, C. P. and L. J. Stadler. 1955. The effect of ultraviolet radiation on the genes and chromosomes of higher organisms, p. 249-284. In Hollaender, A. (ed.), Radiation Biology, Vol. 2. McGraw-Hill, New York.

116. Terskikh, V. V. 1965. The mitotic cycle in a UV-irradiated cell culture. Doklady Akad. Nauk. S. S. S. R. (Biology Section) 163: 217-220. (English translation 163: 427-430).

117. Todd, P., T. P. Coohill and J. A. Mahoney. 1968. Responses of cultured Chinese hamster cells to ultraviolet light of different wavelengths. Radiat. Res. 35: 390-400.

118. Trosko, J. E., E. H. Y. Chu and W. L. Carrier. 1965. The induction of thymine dimers in ultraviolet-irradiated mammalian cells. Radiat. Res. 24: 667.

119. Trosko, J. E. and M. R. Kasschau. 1967. Study of pyrimidine dimers in mammalian cells surviving low doses of ultraviolet radiation. Photochem. Photobiol. 6: 215-219.

120. Wacker, A. 1963. Molecular mechanisms of radiation effects, p. 369-399. In Davidson, J. N. and W. E. Cohn (eds.), Progress in nucleic acid research, Vol. 1. Academic Press, New York.

121. Wacker, A., D. Weinblum, L. Traeger and Z. H. Moustafa. 1961. Photochemische Reaktionen von Uracil und Uridin. J. Mol. Biol. 3: 790-793.

122. Wang, S. Y. 1961. Photochemical reactions in frozen solutions. Nature 190: 690-697.

123. Ward, H. M. 1893. Further experiments on the action of light on Bacillus anthracis. Proc. Roy. Soc. London 53: 23-44.

124. Wheeler, S. M., H. S. Ingraham, A. Hollaender, N. D. Lill, J. Gershon-Cohen and E. W. Brown. 1945. Ultraviolet light control of airborne infections in a naval training center. Am. J. Public Health 35: 457-468.

125. Wierzchowski, K. L. and D. Shugar. 1962. Photochemistry of model oligo- and polynucleotides. IV. Heterooligonucleotides and high molecular weight single and twin-stranded polymer chains. Photochem. Photobiol. 1: 21-36.

126. Withrow, R. B. and A. P. Withrow. 1956. Generation, control, and measurement of visible and near-visible radiant energy, p. 125-258. In Hollaender, A. (ed.), Radiation Biology, Vol. 3. McGraw-Hill, New York.

127. Witkin, E. M. 1966. Mutation and the repair of radiation damage in bacteria. Radiat. Res. (Suppl. 6): 30-51.

128. Witkin, E. M. 1967. Mutation-proof and mutation-prone modes of survival in derivatives of Escherichia coli B differing in sensitivity to ultraviolet light. Brookhaven Symp. Biol. 20: 17-53.

129. Wulff, D. L. 1963. Kinetics of thymine photodimerization in DNA. Biophys. J. 3: 355-362.

130. Wulff, D. L. and C. S. Rupert. 1962. Disappearance of thymine photodimer in ultraviolet-irradiated DNA upon treatment with a photoreactivating enzyme from bakers' yeast. Biochem. Biophys. Res. Comm. 7: 237-240.

131. Zeitz, L., R. Ferguson and E. Garfinkel. 1968. Radiation-induced effects on DNA synthesis in developing sea urchin eggs. Radiat. Res. 34: 200-208.

132. Zelle, M. R. and A. Hollaender. 1955. Effects of radiation on bacteria, p. 365-430. In Hollaender, A. (ed.), Radiation Biology, Vol. 2. McGraw-Hill, New York.

133. Zirkle, R. E. and R. B. Uretz. 1965. Disassembly of mitotic organelles with subcellular microbeams. In M. D. Anderson Hospital and Tumor Institute, 18th Symposium on Fundamental Cancer Research, Proceedings, Cellular Radiation Biology. Williams and Wilkins, Baltimore.

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William M. Leach
Division of Biological Effects, Bureau of Radiological Health, DHEW (BRH/DBE 70-3; 30 pp; 133 ref).

A summary of the potentially deleterious biological effects of ultraviolet radiation is presented from subcellular to organismal levels. Critical organs and applicable exposure standards are presented. Production of ultraviolet radiation is summarized. Absorption of ultraviolet by biologically important systems is distinguished from the action of ultraviolet on the system.

KEY WORDS:
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